FREQUENCY ANALYZED LASER LIGHT SCATTERING (FALLS)

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ABSTRACT

A simple and robust light scattering technique for spray diagnostics was developed. The technique provides a spray's intact length and breakup frequency. Scattered light is collected from a laser sheet that illuminates a portion of the spray. The scattered light is imaged on a fast photodiode whose output is sampled at 20 kHz. Fast Fourier transform analysis is performed on the sampled signal. The shape of the FFT produced can be correlated to one of three distinct spray regimes: intact sheet, ligaments, or droplets. Strobe and laser illuminated photographs are also shown for reference.

INTRODUCTION

The primary disintegration of a liquid sheet may be summarized into three regions [1,2]. The first region is composed of the intact liquid sheet where waves form on the surface of the sheet and grow in amplitude. The shedding of ligaments forms the second region. In the third region, the ligaments themselves become unstable and break into large droplets. Aerodynamic forces cause further disintegration of the large droplets. The optical technique developed by the authors can spatially locate the three stages of primary atomization by correlating them with distinct shapes of fast Fourier transformation (FFT) graphs.

HARDWARE SETUP

Swirl Coaxial Injector

A swirl coaxial injector was used to create a swirling conical sheet. A cross sectional schematic is presented as Figure 1. Swirl is introduced into the post via a tangential entry swirl bolt into which three slots have been cut. The bolt is drilled axially from the exit to the slots. It is screwed into a large opening in the injector body and seats at the top of the injector post such that the swirled liquid exits the bolt and travels down the post (ID = 3mm, OD = 4mm). The entire injector assembly is completed when the injector body is inserted into the air supply plenum. An exploded view of this arrangement is shown in Figure 2. The diameter of the gas orifice is 10mm.

The injector was installed into a water/compressed air spray rig. Pressurized water was forced from a run tank through the injector. The water was received into a catch basin to be reused.

Shop air (830 kPa) was used as the pressurant. All experiments were run with a water mass flow rate of 0.1 kg/s. Coaxial air was not used for the work reported herein.

Photography Setup

A manually operated 35 mm camera was used to photograph the spray. The camera was bolted to the optical table using an optics post. Photographs were taken using 400 ASA color film. The camera was set at a shutter speed of 1/30th of a second, f=4.9, and the strobe light operated at 30 Hz. The camera was not electronically coupled to the strobe light. On average, 90% of the photographs worked perfectly. Occasionally two strobe flashes were captured on a single photograph. This would occur when the shutter was just opening as the first strobe flash occurred and just closing as the second flash occurred. A schematic is shown in Figure 3.

Light Scattering Setup

The laser light scattering experiment requires four basic components: a laser (or any other light source), lenses for transforming the light into a thin narrow sheet, a fast response photodiode, and a PC for data acquisition. A sketch of this arrangement is shown in Figure 4.

The argon ion laser produced approximately 400 mW of light energy. A short focal length lens was used to expand the beam. It was next directed through an optical iris to control its width. The light was focused into a thin sheet by a simple cylindrical lens. Wave structures or ligaments moved through the probe volume and the scattered light was imaged onto the photodiode at a forward scattering angle of 30 degrees off axis. The spray was translated vertically to test various axial locations. Figure 5 shows the light scattering experiment in process.

Michael Lee designed the PC data acquisition and analysis package. It sampled the current through the photodiode at 20 kHz and generated fast Fourier transforms for the raw data files obtained. The processing of these raw data files will be discussed in greater detail later.

DISCUSSION OF EXPERIMENTAL RESULTS

Swirling Sheet Photography

Figure 6 shows the swirling water spray (no coaxial air is added). The field of view is 13 cm wide. Note the amplitude growth of waves and the transition from wave to ligament, and finally to droplet cluster. These regions are identified in the Figure. The laser sliver (probe volume) is located 51mm from the injector tip where the velocity is estimated at 14.2 m/s using downstream phase Doppler particle anemometry. Assuming this, the Weber number of the plain spray is 2300. In actuality, air is induced to flow along with the water, thus reducing the velocity between the water and air.

Figure 7 shows a laser sheet cutting completely through the swirling spray at an axial location of 76mm. The pattern is hollow in the center of the spray and highly concentrated where many droplets are present. The strobe light is also used to illuminate the spray in this image.

Laser Light Scattering

Each 10-second test run produced approximately 50 sets of raw data composed of 4096 points collected during a 205-millisecond window. An FFT was derived from each raw data set. The 50 FFTs were combined to produce a single curve as shown in Figure 8. Dividing the y data by the highest point in the 44mm data set normalizes the y-axis for Figures 8 and 9. This normalization procedure is simple, but still allows the reader to compare data from several runs. A significant amount of noise is still present in the summed FFT curve. The dark line is produced by a smoothing routine included in Kaleidagraph, a standard graphing application produced by Synergy Software. Figure 8 shows a predominance of light scattering activity between 600 Hz and 1100 Hz.

Work by Anderson et alia described a simple method to assess the breakup frequency of a disintegrating liquid sheet [3]. The velocity of the liquid is divided by the relevant distance as measured from a photograph. In this case, the distance between ligaments can be measured directly from Figure 6: approximately 11mm. As previously mentioned, the velocity of the liquid is approximately 14.2 m/s. Using these numbers, one would estimate peak frequency activity to be about 1275 Hz – a little high compared to Figure 8, but still reasonable.

The results of a systematic study downstream of the injector plate are presented in Figure 9. The seven curves have been smoothed using a running average of 101 data points. The results of this smoothing were then normalized in the same way as for Figure 8.

Three basic shapes are observed in the graph. The shapes of the curves indicate the location of three distinct regions in the spray: intact sheet, ligament structures, and droplet clusters. Near the faceplate (25mm, 32mm, and 38mm), the frequency behavior is very nearly flat, but with a very slight hump at 1000 Hertz. It is clear that the disturbances are broadband in this region. This is the sort of FFT produced when waves of many frequencies, but small amplitude, are active on the surface of the intact liquid sheet.

A very different FFT profile is shown slightly farther downstream (44mm and 51mm). Ligaments have separated from the intact sheet and are passing through the laser slice at more distinct frequencies, centering around 800 Hertz. High frequency behavior (representing fast waves on the intact liquid sheet) has diminished and the scattered light favors the low frequency behavior of the passing ligaments.

By 57mm downstream from the faceplate, the ligaments have disintegrated. Their frequency-centered behavior has been "smeared" apart by their disintegration into droplets. This process produces a flatter FFT as the probe volume is moved downstream; compare the 57mm curve to the 64mm curve.

SUMMARY/CONCLUSIONS

Laser light scattering is an effective tool for measuring two important characteristics of a disintegrating sheet: intact length and frequency behavior. The shape of FFTs obtained from the scattered light can be used to locate intact liquid, shed ligaments, and the resulting droplet cloud. When the laser light sheet is located so as to capture the shedding of individual liquid structures, the ligament shedding frequency can be measured by noting the peak in the FFT graph.

REFERENCES

1. A.H. Lefebvre, *Atomization and Sprays,* Taylor and Francis, Bristol, Pennsylvania, 1989.

2. A. Mansour and N. Chigier, Disintegration of Liquid Sheets, *Physics of Fluids A*, vol. 2, number 5, May 1990.

3. W.E. Anderson, H.M. Ryan, and R.J. Santoro, Impinging Jet Injector Atomization, in Yang and Anderson (editors), *Liquid Rocket Engine Combustion Instability*, Chapter 8, AIAA Progress in Astronautics and Aeronautics Vol. 169, 1995.

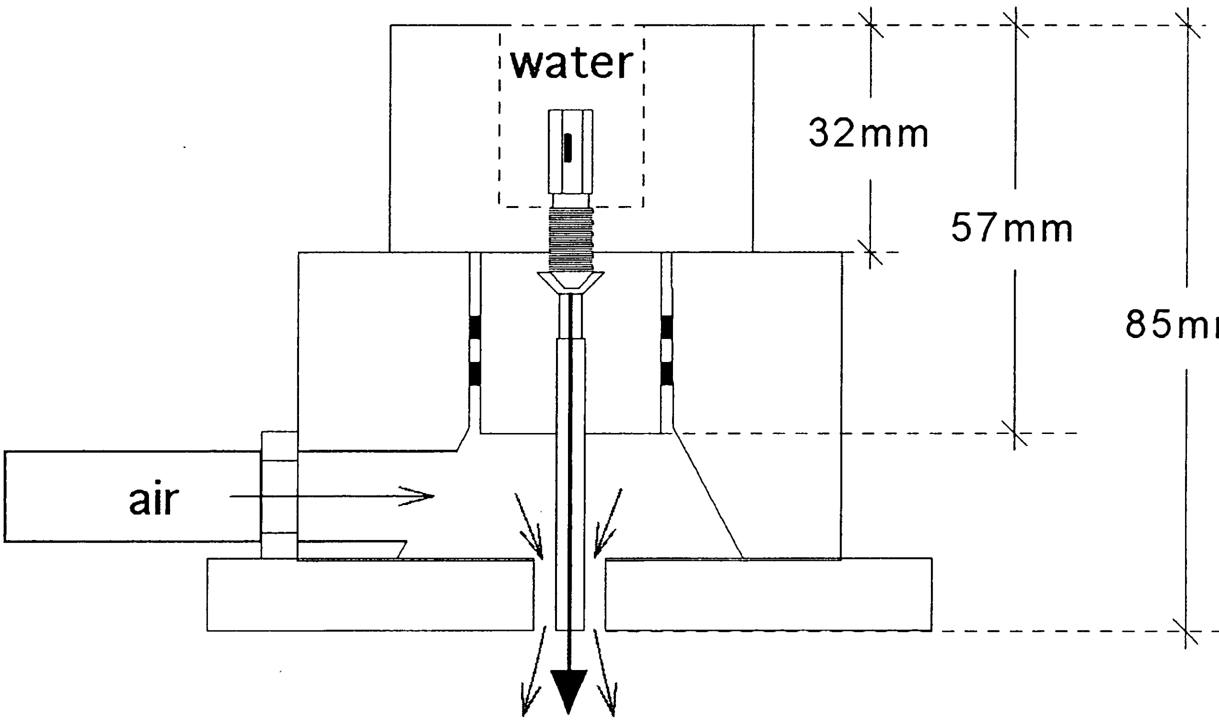

Figure 1: Cross Sectional Schematic of Swirl Coaxial Injector

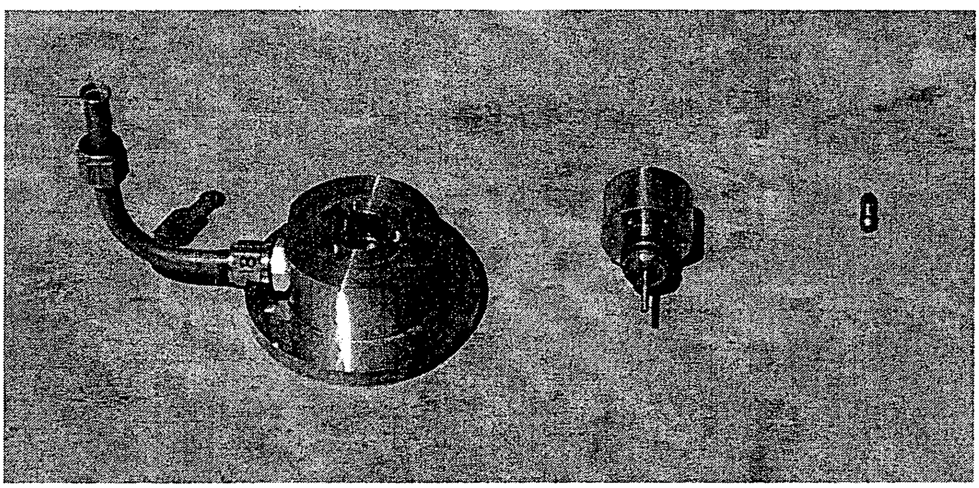

Figure 2: Swirl Coaxial Injector Assembly Components

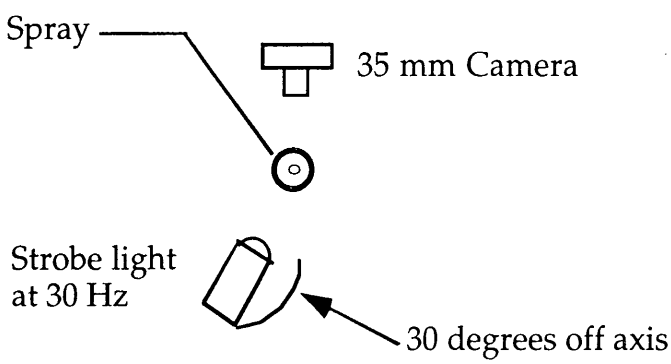

Figure 3: Sketch of Photography Setup

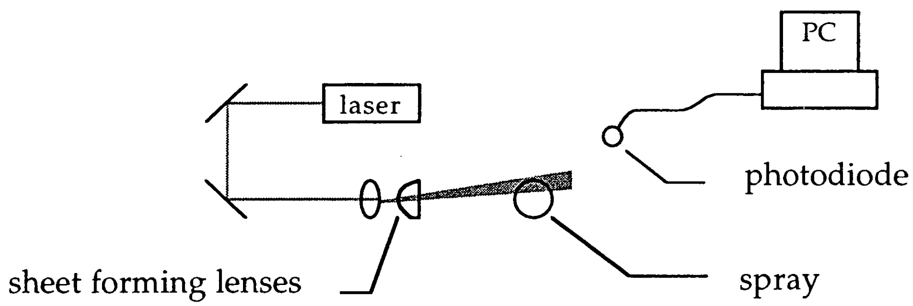

Figure 4: Laser Light Scattering Setup

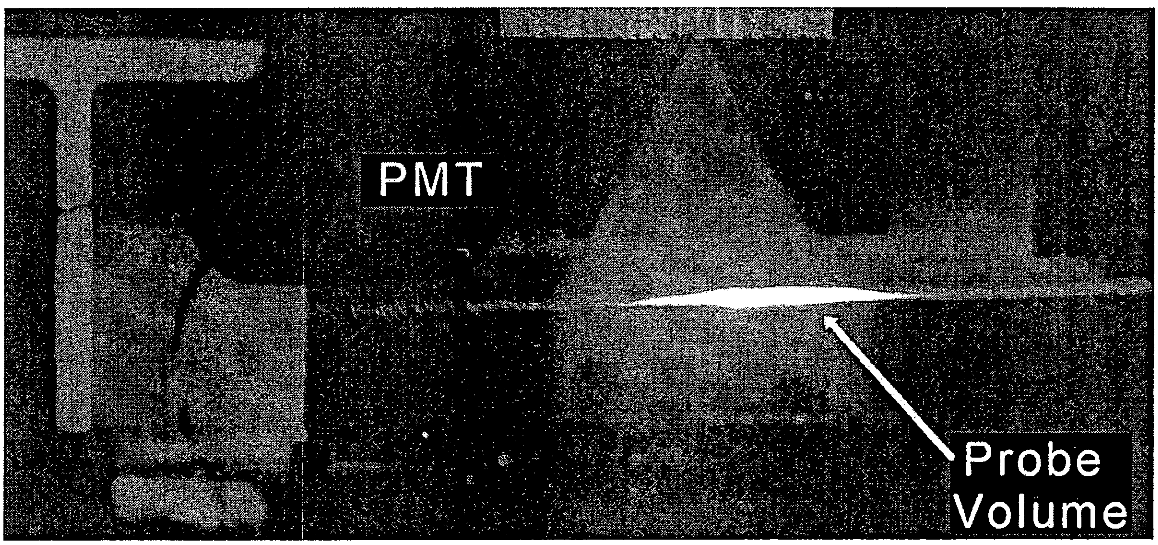

Figure 5: Light Scattering Experiment in Process

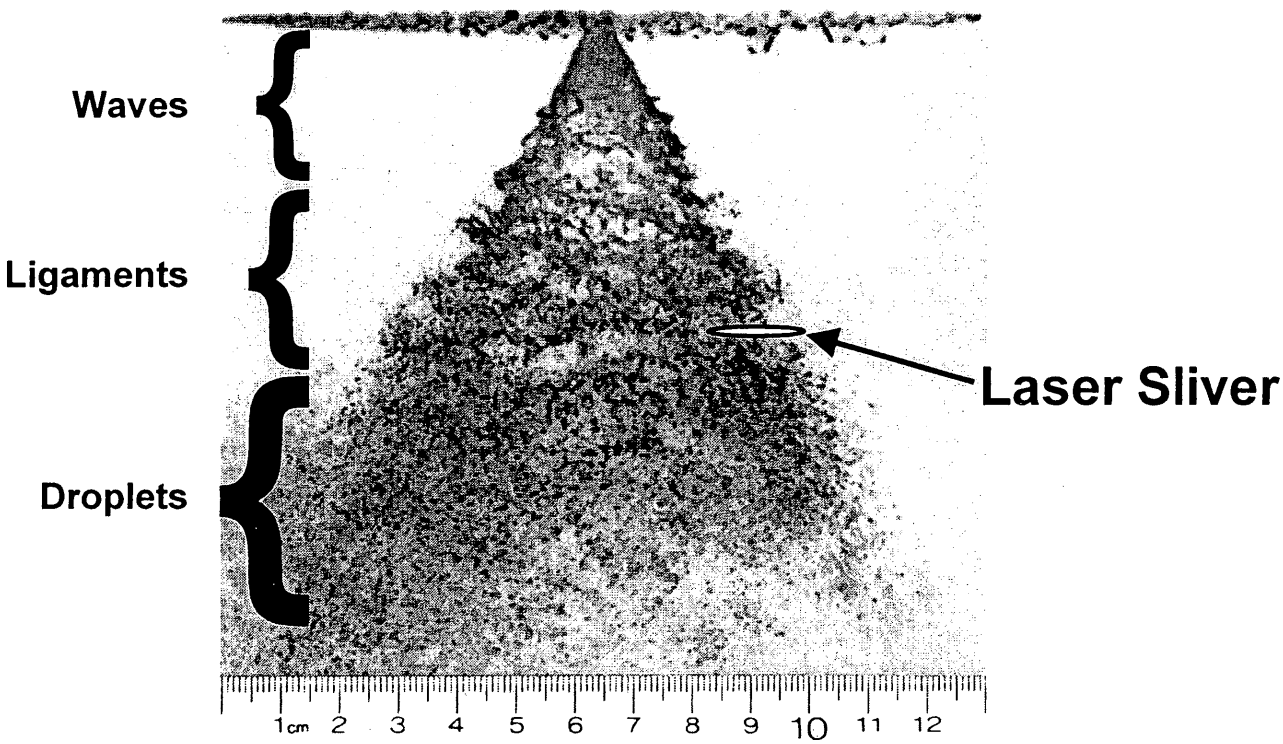

Figure 6: Inverted Photograph of Swirl Water Spray - No Coaxial air is added

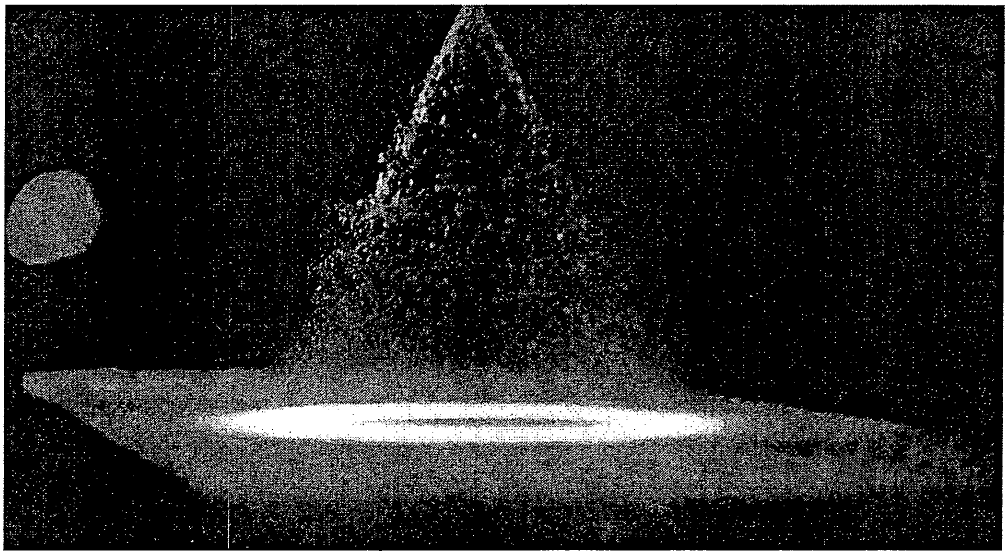

Figure 7: Swirling Water Spray Cut by Laser Sheet at 76mm

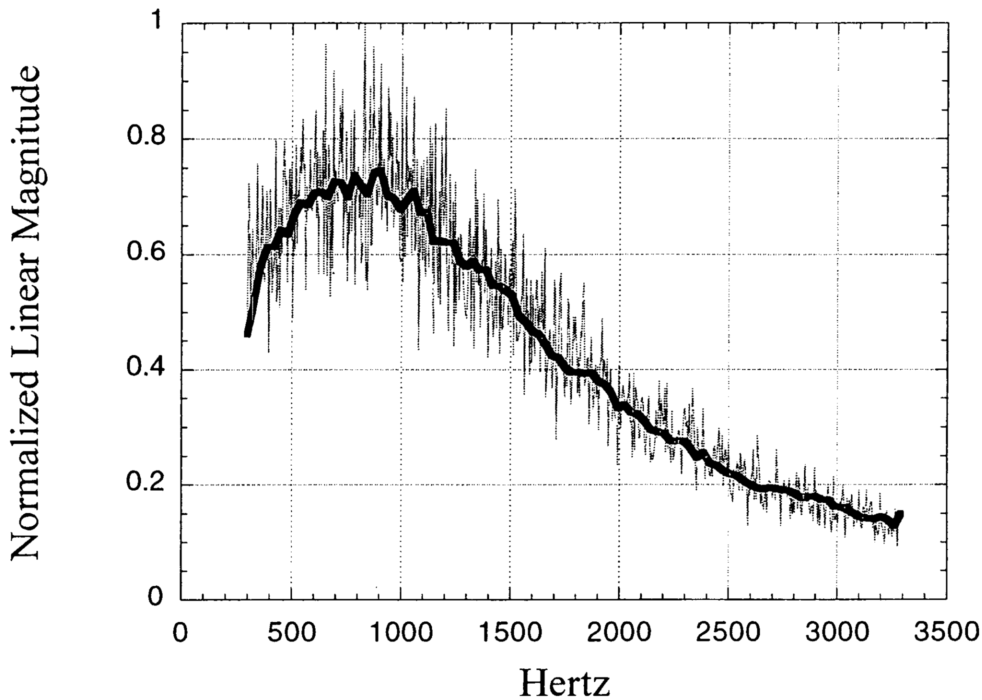

Figure 8: FFT Produced by Scattered Light (44mm downstream from injector plate)

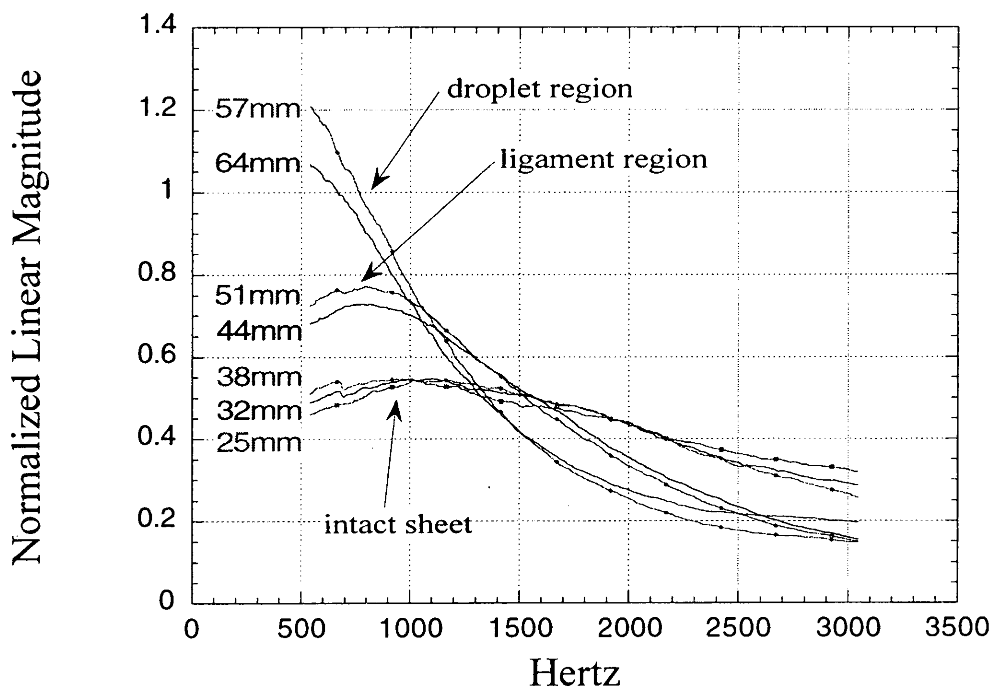

Figure 9: Axial Survey of Scattered Light FFTs